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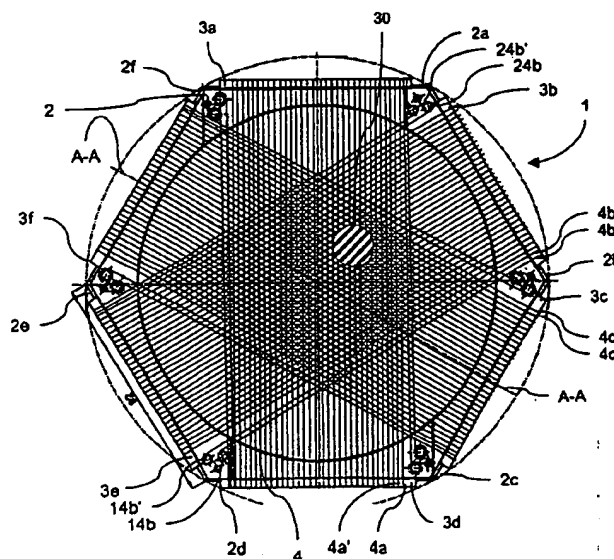online: EPODOC,WPI,JAPIO,INSPEC

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(54) Abstract Title
Device and method for two-dimensional detection of particles or electromagnetic radiation

(57) A device for detecting the position of a particle or electromagnetic pulse comprises a delay-line anode (1) which includes at least first, second and third non-parallel conductive members (4a, 4b, 4c) for receiving electromagnetic pulses (30), each one of the conductive members (4a, 4b, 4c) forming a propagation line for electromagnetic signals and having a first and a second terminating end, at least some of which provide a propagated signal to an electronic analyser. The times of arrival of the progated signal give a measure of the position of the particle. The device may be used as a vacuum detector in an atom probe instrument for microstructural and microchemical analysis of materials, and can be used in combination with a stack of micro-channel plates and a phosphor screen.
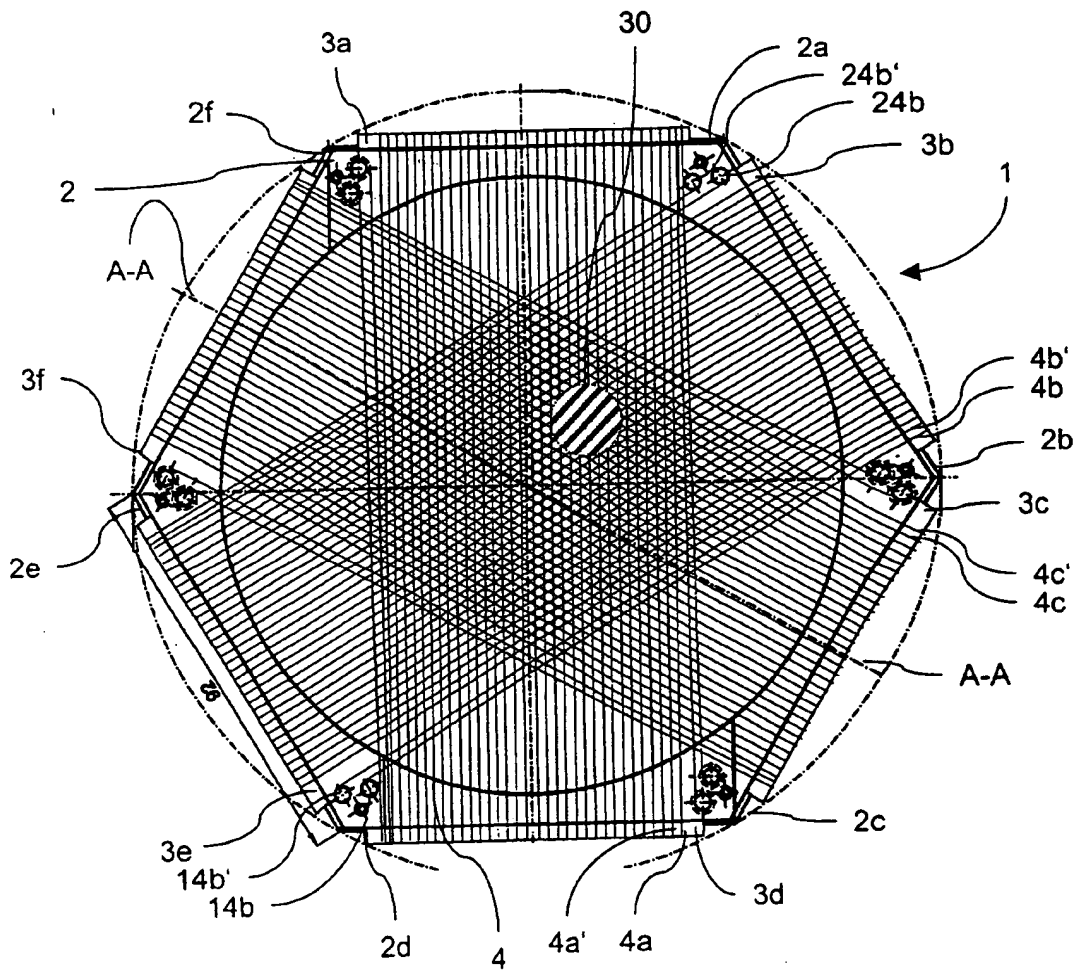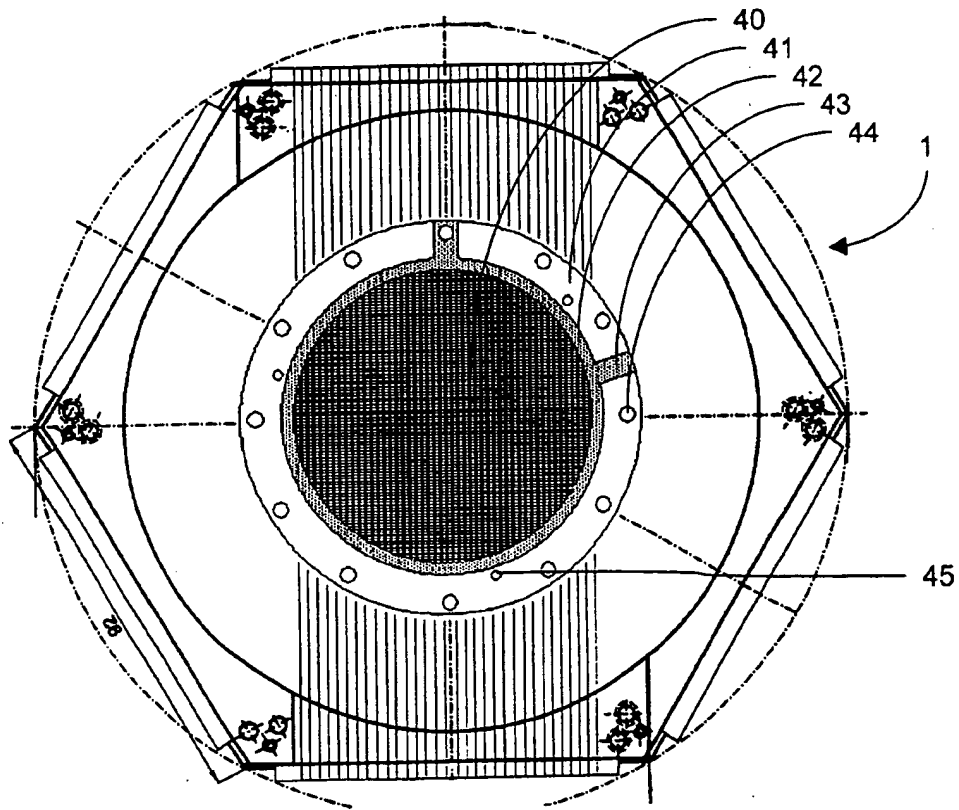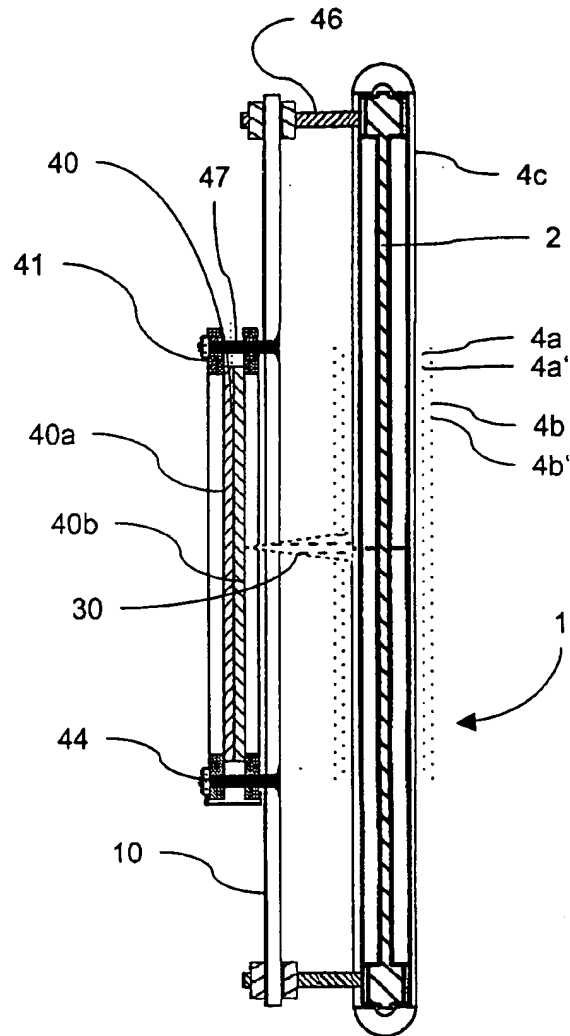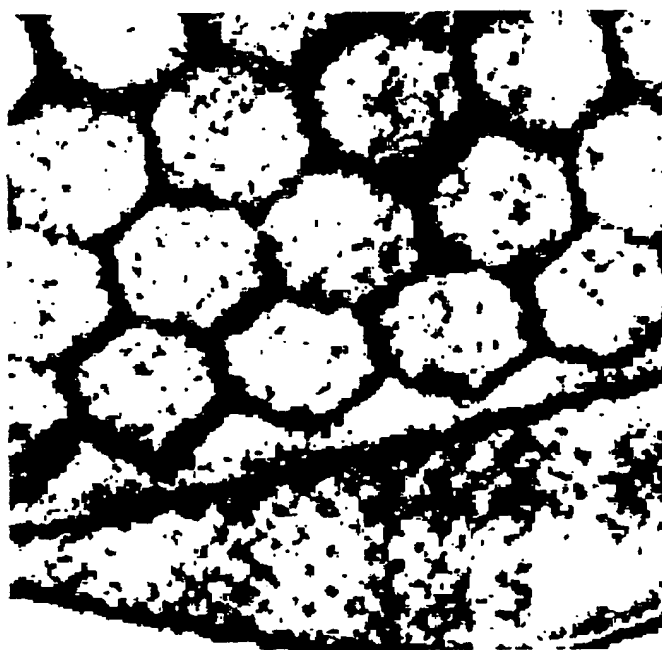
Fig. 1

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Fig. 1

Fig. 2

Fig. 3

Fig. 4

Fig. 5

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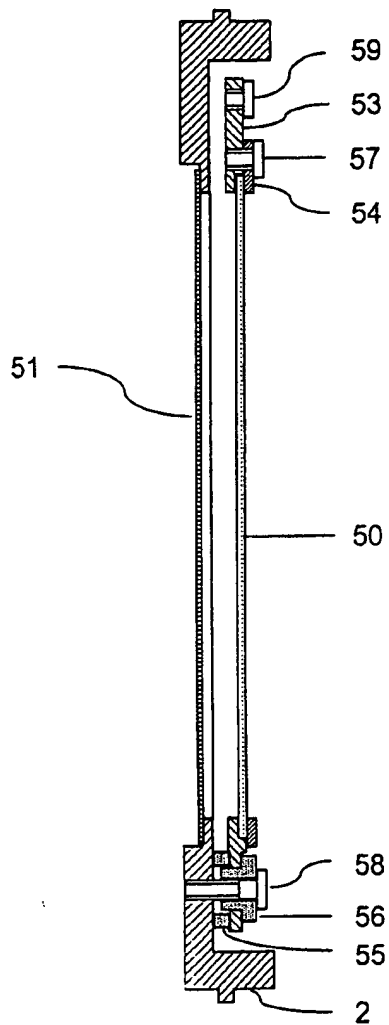50

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Fig. 6

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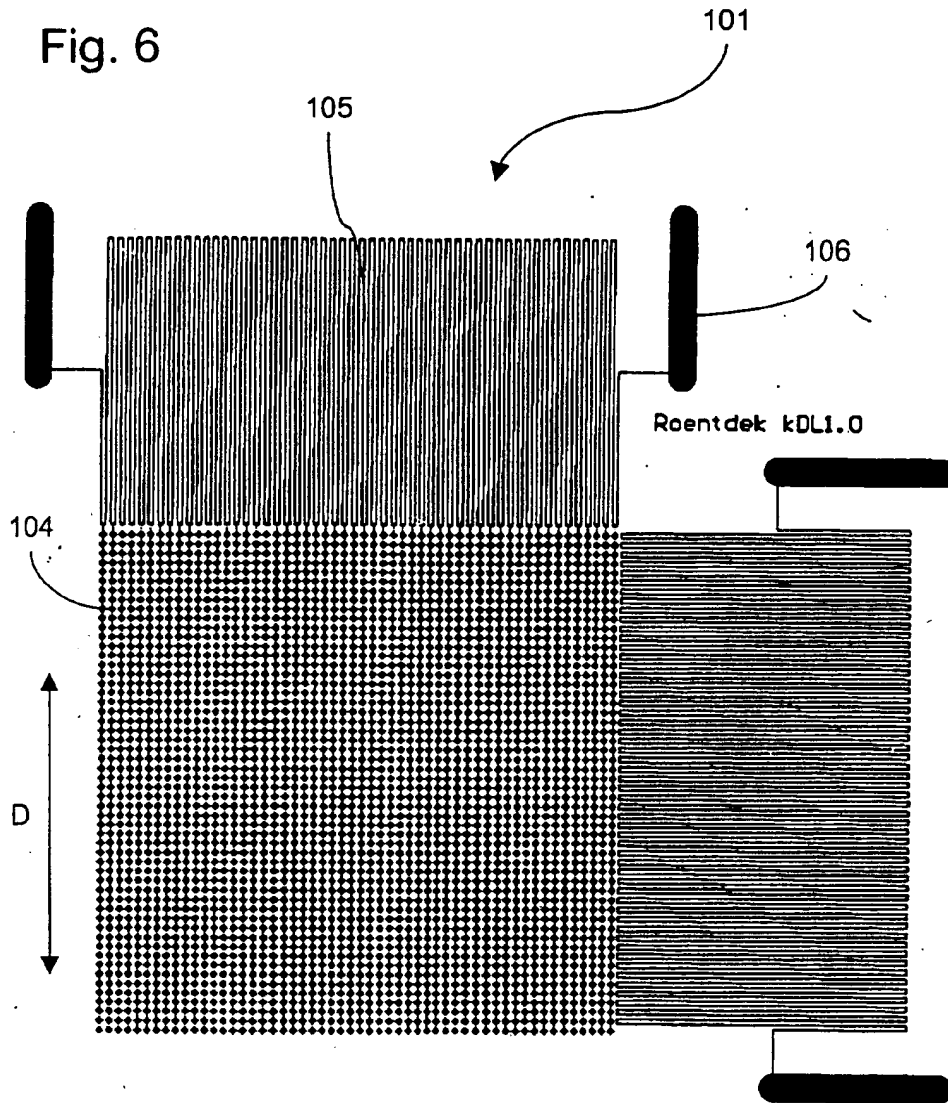
Fig. 7
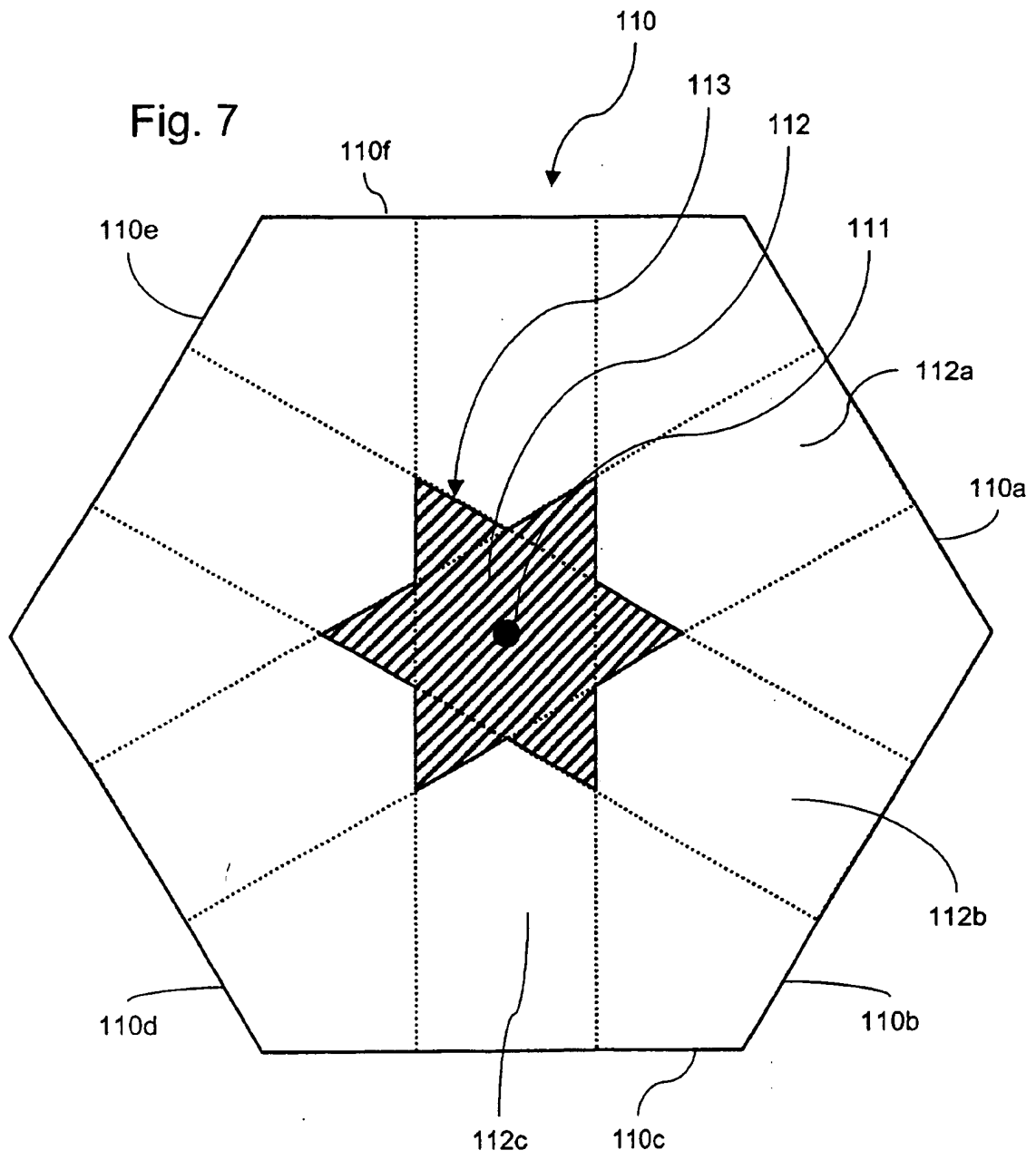
Fig. 8

Device and Method for Two-Dimensional Detection of Particles or Electromagnetic Radiation

5   The present invention relates to a device and method for two-dimensional detection of particles or electromagnetic radiation in single event mode.

Two-dimensional imaging of microscopic particles or electromagnetic radiation is of increasing interest in fundamental and industrial research. For example, in metallurgy and materials science, two-dimensional imaging is used to derive information on the microstructure of a material.

15   A microscopic particle can be an electron, an atom, a molecule, an ion, or the like. As used herein, the term particle is also intended to encompass electromagnetic radiation (in general electromagnetic radiation behaves as a photon having particle-like properties when detected).

It is necessary for many applications to not only detect whether there is a particle, but also to determine the two-dimensional position of the particle. Photographic film has been used to record two-dimensional images of such particles for many decades, for example in the field of field ion microscopy (FIM). The use of video-cameras including CCD-chips for such two-dimensional imaging is also well-known.

Furthermore, for many applications it is necessary to measure the two-dimensional position and the time when the microscopic particle is detected. So called time-of-flight methods measure the time difference between the time when the primary

microscopic particle is created in a reaction or
emitted from a substrate and the time when the
particle hits the detector. For time-of-flight
experiments the primary particle is usually created or
5   emitted from a substrate by a pulsed source, for
example a laser pulse or an electromagnetic pulse
induced on the substrate. This pulse will be referred
to as the initial pulse. The typical flight time of
microscopic particles is of the order of several
10   nanoseconds to microseconds and, consequently, a
precision of the order of one nanosecond or even less
needs to be achieved for the time measurement.

A position-sensitive detector commonly used for
15   two-dimensional imaging and for time-of-flight
applications is a delay-line detector. The delay-line
detector includes a stack of micro-channel plates
(MCP) and a delay-line anode. A MCP or a stack
thereof is a position-sensitive secondary electron
20   multiplier. A standard MCP is from about 25 to 100 mm
in diameter, about 1 mm thick and comprises hundreds
of thousands or even millions of pores. A voltage of
about 1000 V is applied over each MCP. When a primary
incident particle impinges in one of the pores it
25   starts an avalanche process by secondary electron
multiplication in the pore due to the high electric
field inside it. As a result of the high voltage
necessary for secondary electron multiplication the
MCP can only be used in high vacuum at less than about
30   10^{-5} mbar. The primary particle is converted into a
cloud of about 1000 to 10000 electrons in this single
pore. Several of the MCPs are stacked to increase the
amplification factor. Using a stack of two or three
is common for single particle detection. The MCPs are
35   preferably mounted directly on to each other. The
avalanche distributes to a few pores when reaching the
second and third MCP, because the pores of different

MCPs are not aligned. But the secondary electron
cloud is still spatially very localised in a few of
the pores. The electron cloud leaving a stack of
three MCPs typically contains 10^6 to 10^7 electrons.

5   The electron leaving the rear side (facing the delay-
line anode) of the MCP stack is accelerated onto the
anode.

An example of a delay-line anode is a crossed

10   wire anode. A crossed wire anode typically comprises
a square metallic substrate acting as a holder, four
insulating ceramic rods and two metallic wires. A
ceramic rod is mounted on each edge of the square
metallic holder and the first wire is wound around the

15   metallic holder on the rods in one direction (x-
direction), whereas the second wire is wound
perpendicular to the first one (y-direction). All
wires are insulated from the metallic holder and from
each other by the rods. The metallic wires form a

20   crossed mesh with a wire distance of about 0.5 mm.
The electron cloud leaving the rear side of the MCP-
stack is collected by the wires being typically 100 V
more positive than the rear side of the MCP-stack
inducing an electromagnetic signal. The signal is

25   propagating along each wire in both directions. Four
analogue amplifiers connected to the four terminating
ends of the two wires amplify the signals arriving at
the four terminating ends. A timing signal is picked
up at the MCP and is amplified by a fifth amplifier.

30   In a pure imaging application, four clocks realised by
time-to-digital-converter channels (TDC) are started
with the signal from the MCP. Each of the TDC
channels is stopped by the signal of one of the other
four amplifiers. The TDC directly converts the time

35   difference between a start and a stop signal of each
channel to a digital number which can be further
processed with a computer. Thus, the method yields

the signal propagation times on the two wires from the position where the cloud has hit the crossed wires to the terminating ends in the positive and negative x-directions (tx1 and tx2) and to terminating ends in

5   the positive and negative y-directions (ty1 and ty2).
Knowing the mean propagation speed (v) of the signal, the two-dimensional position where the electron cloud has hit the crossed wires can be reconstructed by a simple algorithm. The position in the x-direction (x)

10   is a linear function of the times tx1 or tx2 and the position in the y-direction (y) is a linear function of the times ty1 or ty2. The position in the x-direction is also given by the time difference x = v/2 * (tx2 - tx1) and the position in the y-

15   direction (y) by the difference y = v/2 * (ty2 - ty1).
The typical position resolution of such a delay-line detector is 0.1 mm and the total propagation time (T) of the signal on a wire from one terminating end to the other is typically from 30 to 100 ns. All this

20   information is stored for each single primary particle by a computer. Thus, a delay-line detector yields the two-dimensional position of each single primary particle and not only an integrated image (as, for example, a CCD-camera does) of many particles (such a

25   detection method is called single event mode).
However, when two particles impinge on the detector within a shorter time difference than T it may occur that a signal of the second particle arrives at a terminating end before the respective signal of the

30   first particle due to different positions. To register such particles at all a so called multi-hit TDC is used. A multi-hit TDC registers more than one stop signal on each channel after each start signal.
When first and second primary particles impinge on the

35   detector during T, two stop signals and hence two times are registered at each of the TDC channels following the identical start pulse as before. In

principle, therefore, the multi-hit TDC enables two
particles to be detected with a shorter time distance
than T. However, a typical multi-hit TDC has a dead
time for two consecutive stop signals of about 20 ns.
5   When the second signal arrives at a terminating end
within this dead time after the first signal the
second signal is lost. Whether or not this occurs
depends on the time difference between the first and
the second particles and on their positions. If all
10   of the four times tx1, tx2, ty1, and ty2 are
registered for each of the two particles the position
of both particles can be determined uniquely as long
as the particles do not arrive at the detector at the
same time within the time resolution of the TDC,
15   typically from 0.5 to 1 ns. However, if one of the
four times of the second particle is lost due to dead
time the position reconstruction for the respective
dimension fails. The mean time difference wherein the
positions of two particles can be determined is known
20   as the mean pulse-pair resolution. Such a detection
set-up has a mean pulse-pair resolution that is
substantially equivalent to the dead time of the TDC,
i.e. approximately 20 ns. This restricts the maximum
count rate detectable for a reasonable error rate to
25   less than 50 MHz. This is disadvantageous since for
higher count rates, which would be desirable, nearly
all positions of particles are lost due to dead time.

For time-of-flight applications, the situation is
30   similar. An additional fifth TDC channel is used to
register the time-of-flight. The five TDC-channels
are started with the initial pulse and one of the TDC
channels is stopped by a timing signal picked-up at
the MCP and the other four by the signals from the
35   terminating ends of the two wires. Therefore, the
time of flight of the primary incident particle is
given by the fifth TDC-channel. The typical

resolution for the time-of-flight measurement is about a nano-second. In time-of-flight applications, two particles are often detected within a single pulse cycle, i.e. are created by the same initial pulse, and

5   in this case a multi-hit TDC is used. Again, the multi-hit TDC is started by the initial pulse and the TDC registers more than one stop signal without having a new start. When a first and a second primary particle impinge on the detector after a single start

10   pulse, two stop signals and hence two times are registered at each of the TDC channels following the identical start pulse, which are:

at the first terminating end of the first wire:
15   $tx1a$ and $tx1b$;
at the second terminating end of the first wire:
$tx2a$ and $tx2b$;
at the first terminating end of the second wire:
$ty1a$ and $ty1b$;
20   at the second terminating end of the second wire:
$ty2a$ and $ty2b$; and
at the MCP pickup: $tofa$ and $tofb$,

where a denotes the first and b the second
25   registered time.

Again a typical TDC has a dead time of about 20 ns for two consecutive stops on the same channel. When two particles hit the detector within a time

30   distance of the dead time of the TDC $tofb$ is lost. Then the time-of-flight of the second particle cannot be determined by the fifth TDC channel. However, the time-of-flight of the second particle may still be determined by the sum $tx1b + tx2b = sumxb$ or $ty1b +$

35   $ty2b = sumyb$. But when additionally $tx1b$ or $tx2b$ and $ty1b$ or $ty2b$ are lost due to the TDC dead time, this reconstruction fails and the time-of-flight of the

second particle cannot be determined at all. When even three or more of the times tx1b, tx2b, ty1b and ty2b are lost due to the dead time, the position reconstruction also fails. Thus, the position and time-of-flight determination using such an anode also has a dead time of about the dead time of the TDC.

The situation is exacerbated in time-focussed instruments when two ions arrive with the same flight time, within the timing resolution of the TDC, typically 0.5 to 1 ns. In this case, none of the times tx1a, tx2a, ty1a, ty2a, tx1b, tx2b, ty1b, ty2b may be lost and, therefore, one achieves two x and two y positions, but it will be impossible to link the two x position measurements and the y positions to the first and second particles. In other words, it is not known which x-position belongs to which y-position. This means that neither the position of the first nor of the second particle can be determined, although all of the eight times tx1a, tx2a, ty1a, ty2a, tx1b, tx2b, ty1b, ty2b are measured.

The mean pulse-pair resolution for such a time-of-flight experiment using a common crossed wire anode is also approximately 20 ns due to the above described disadvantages of losing information when two particles arrive closely after each other.

An example of a time-of-flight device used in metallurgical and materials science research is an atom probe (AP). The atom probe is a microanalytical instrument capable of analysing solid materials at the atomic scale. Three-dimensional atom probes (3DAP) permit the elemental reconstruction of a small volume of a solid specimen with near atomic resolution. A detailed account of the atom probe and its use in the microstructural and microchemical analysis of

materials is provided in *Atom Probe Field-Ion Microscopy*, M.K. Miller, A. Cerezo, M.G. Hetherington and G.D.W. Smith, Oxford University Press, 1996 and *Atom Probe Microanalysis: Principles and Applications to Materials Problems*, M.K. Miller and G.D.W. Smith, Materials Research Society, Pittsburgh, PA, 1989. For atom probe analysis a strong and short initial electromagnetic pulse is applied to a very sharp specimen, which will typically be formed from a metal, alloy or semiconductor material. The pulse causes an emission of primary ions from the surface of the specimen by field evaporation. A position sensitive detector is located opposite to the specimen, which detects the position and the time of the arrival of the primary ions. By the detected position, the position on the surface of the specimen from which an ion was emitted may be determined. By the time-of-flight, the charge-to-mass-ratio may be determined, and hence the ion species. Repeating the process by applying a sequence of many electromagnetic pulses allows the three-dimensional atomic structure of the specimen to be determined.

A further development of a crossed wire anode includes a first pair of wires in the x-direction and a second pair of wires in the y-direction (a general description of crossed wire anodes is provided in S.E. Sobottka and M.B. Williams, IEEE Trans. Nucl. Science 35:348, 1988). The first wire (reference wire) of each pair is typically about 100 V more positive than the rear side of the MCP. The second wire of the same pair (signal wire) is typically about 200 V more positive than the rear side of the MCP. Thus, the electron cloud emerging from the MCP is mostly collected by the signal wire. Such a wire pair is known as a Lecher line. Using a Lecher line avoids loss of signal during propagation on the wire in a

manner similar to a shielded coaxial cable. However, each wire pair forming a Lecher line forms only one signal propagation line, sufficient for the reconstruction of the spatial position in one

5   dimension. Thus, the two perpendicular wire pairs are generally equivalent to two perpendicular single cables with respect to the position determination. Accordingly, a single wire and a wire pair both form a single signal propagation line.

10

    Other delay-line anodes use two printed metallic circuits or other two signal propagation lines to collect the electron cloud and propagate the induced signal instead of the crossed wires.

15

    All of the above delay-line anodes have the disadvantage with respect to pulse-pair resolution, since the general method for the position determination is equivalent.

20

    This disadvantage also applies to multi-wire detectors such as those used in position-sensitive avalanche detectors used for nuclear experiments (see A. Breskin, Nucl. Inst. and Meth. 196 (1982) 11) since

25   these also use two sets of parallel wires to determine the x and y ordinates independently.

    In the separate field of molecular ion structure analysis, the problem of ambiguities for determining

30   positions of particles arriving simultaneously has been considered by W. Koenig et al., Nuclear Instruments and Methods in Physics Research B10/11 (1985) 259-265, Elsevier Science Publishers B.V. Koenig et al. propose using three sets of parallel

35   wires, which requires a total of 870 signal connections. It will be appreciated that such an arrangement would not be practical for a vacuum

detector as used in, for example, an atom probe microanalyser. 870 preamplifiers are also required and this means that the design is very complex and costly. Koenig et al. are, furthermore, not concerned

5   with the issue of improving multi-hit properties and mean pulse-pair resolution.

The present invention aims to provide a delay-line anode and a method for detecting the position

10   and/or the time of particles with improved multi-hit properties and/or improved mean pulse-pair resolution.

Accordingly, the present invention provides a device for detecting the position of a particle

15   comprising a delay-line anode which comprises at least a first, second and third non parallel conductive members for receiving electromagnetic pulses each of the conductive members forming a propagation line for electromagnetic signals and each of the conductive

20   members having a first and second terminating end at least some providing a propagated signal to analysing electronic circuits.

The device according to the present invention may

25   be used as a vacuum detector in an atom probe instrument for microstructural and microchemical analysis of materials, such as metals, alloys and semiconductors.

30   The present invention also provides a method for detecting the spatial position of an electromagnetic pulse, which method comprises the following steps:

        (a)   providing at least a first, second and a third conductive member (4a, 4b, 4c)

35   having each a first and second terminating end;

        (b)   receiving the electromagnetic pulse on a

portion (30) of said first, second and/or
third conductive members (4a, 4b, 4c);

(c)   propagating said electromagnetic pulse on
said conductive members (4a, 4b, 4c); and

5   (d)   determining the local position of said
portion(30) of said first, second and/or
third conductive members by measuring the
time of the arrival of said
electromagnetic pulse at said first and/or
10   second terminating ends.

The method according to the present invention may
be applied to the microstructural and microchemical
analysis of materials, such as metals, alloys and
15   semiconductors.

The device and method according to the present
invention result in a mean pulse-pair resolution which
is significantly smaller than that associated with the
20   prior art crossed wire delay-line anode.

The device according to the present invention
preferably comprises a delay-line anode including
three or more longitudinally extended conductive
25   members which are not parallel to each other, each
member having two terminating ends and capable of
yielding redundant position information. The
conductive members will typically be a signal
propagation line, for example a single wire or a wire
30   pair, preferably metallic wires. The conductive
members are provided to receive an electromagnetic
pulse, whereby the pulse is propagated along the
conductive members in the direction of the two
terminating ends thereof.

35

Two non-parallel conductive members are used to
determine the two-dimensional position of the induced

signal on the anode. It has surprisingly been found
that the additional and redundant position information
resulting from those third or more additional
conductive members can be used for a significant and
5   advantageous improvement of the mean pulse-pair
resolution of the device.

The further description of the device according
to the present invention is restricted to three
10   conductive members for the sake of clarity. It will,
however, be appreciated that it is also advantageous
to use four, five, or even more conductive members,
yielding even more redundant information, being
especially advantageous when more than two particles
15   are detected.

In a preferred embodiment, the device according
to the present invention comprises a stack of MCPs and
the electromagnetic signal induced on the conductive
20   members is caused by an electron cloud leaving the
stack of MCPs after a primary incident particle has
impinged on the stack of MCPs. Each conductive member
is longitudinally extending and preferably comprises a
metallic wire. The signal is propagated along the
25   conductive members in both directions to the
terminating ends. Preferably, an amplifier is
assigned to each of the terminating ends of the
conductive members for amplification of the induced
signal. Preferably, a discriminator, for example a
30   constant-fraction-discriminator, is used for precise
timing of the signals. A stop channel of the TDC is
preferably assigned to each of the discriminators
registering the time between a given start pulse and
the output signal from the constant-fraction-
35   discriminator.

In a preferred embodiment for 2-dimensional

imaging without flight-time measurement, a multi-hit
TDC with at least six channels is used, started with
the pickup from the MCP. The three conductive members
yield the respective times for two consecutive induced
signals by two primary particles ("a" indicates the
first TDC stop signal and "b" indicates the second TDC
stop signal, "1" indicates the first terminating end
of a conductive member and "2" indicates the second
terminating end):

txla, txlb, tx2a, tx2b at the first conductive
member;
tyla, tylb, ty2a, ty2b at the second conductive
member; and
tzla, tzlb, tz2a, tz2b at the third conductive
member.

The position of the induced signal is determined
by the time differences at opposite terminating ends
of the same wire:

xa = vx * (txla - tx2a), ya = vy * (tyla - ty2a)
and za = vz * (tzla - tz2a) for the first
particle; and

xb = vx * (txlb - tx2b), yb = vy * (tylb - ty2b)
and zb = vz * (tzlb - tz2b) for the second
particle,

where vx, vy and vz are the mean signal
propagation velocities on the respective
conductive members.

Each one of the coordinates xa, ya, and za is
linearly dependent from the two others as well as each
one of the coordinates xb, yb, and zb is linearly
dependent from the two others. Therefore, each two of

xa, ya, and za and each two of xb, yb, and zb are enough to determine the two-dimensional position of each particle. Thus, even if one of the times of the second particle is lost, the position of both

5   particles is determined. Even if two particles are impinging on the detector at the same time there is a large probability, due to the propagation time on the conductive members, that at least two of the three time differences xb, yb and zb of the second particle

10   will be detected.

It has surprising been found that the mean pulse-pair resolution can be improved by a factor of up to ten compared with the prior art crossed wire anode for

15   a given error rate. The maximum detection rate for a given error rate is therefore improved by a factor of up to 10 with the device according to the present invention compared with a conventional crossed wire delay-line detector.

20

In a preferred embodiment for a time-of-flight application, a multi-hit TDC with at least seven channels is used, started with the initial pulse. A primary particle impinging on a stack of MCPs is

25   converted into a cloud of electrons inducing an electromagnetic signal on the conductive members. Six of the seven channels are stopped by the signals arriving at the six terminating ends of the three conductive members and the seventh is stopped by the

30   MCP pickup signal. The three conductive members yield the respective times for two consecutive induced signals by two primary particles ("a" indicates the first TDC stop signal and "b" indicates the second TDC stop signal, "1" indicates the first terminating end

35   of a conductive member and "2" indicates the second terminating end:

txla, txlb, tx2a, tx2b at the first conductive
member;
tyla, tylb, ty2a, tylb at the second conductive
member;

5   tzla, tzlb, tz2a, tzlb at the third conductive
member; and
tofa and tofb at the MCP pickup.

Even if, for example, tofb, txlb and tylb are
10   lost, the geometry of the delay lines mean that it is
very likely that tzlb and tz2b are still detected and
the time-of-flight of the second particle can be
reconstructed by sumzb = tzlb + tz2b. It is very
unlikely to lose also sumzb in so far as it is much
15   more unlikely to lose three sums than only two. Thus,
for many pairs of particles impinging on the detector
the dead time is significantly reduced.

With this method and a detector according to the
20   present invention a mean pulse-pair resolution of
approximately 10 ns or less, preferably approximately
5 ns or less, more preferably approximately 2 ns or
less can be achieved.

25   In the case of ions arriving with identical
flight times, where a prior art crossed wire anode
cannot provide any position or time-of-flight for any
particle, the device according to the present
invention provides the two-dimensional positions and
30   time-of-flight of both particles uniquely. When the
two particles are spatially separated enough the
times: txla, txlb, tx2a, tx2b, tyla, tylb, ty2a, tylb,
tzla, tzlb, tz2a, tzlb can be measured yielding
unique x and y positions for each ion. Also the time-
35   of-flight of both particles is known by, for example,
sumxa = txla + tx2a. In this case, even a pulse-pair
resolution of zero can be achieved.

In a preferred embodiment the conductive members comprise a pair of conductors, preferably metallic wires forming a Lecher line for better signal

5   transmission on the lines. The wires are preferably wound around a metallic base plate and are supported by a dielectric, preferably in the form of ceramic rods. One conductive member of each pair is preferably about 100 V more positive than the rear

10   side of the MCP stack, and the other one about 200 V more positive. Differential amplifiers are preferably used for the amplification of the signals arriving at the terminating ends of the conductive members. A differential amplifier includes two inputs and the

15   difference signal between the two inputs is amplified. Advantageously, any noise on the wires is suppressed.

It is advantageous to determine the position by the time differences for example tx1a - tx2a or tx1b -

20   tx1b whenever possible because this exploits the resolution of each of two TDC-channels. Using the time difference may therefore improve the detector resolution by up to a factor of two.

25   Preferably, the position of one or more primary particles is determined in two dimensions for two-dimensional imaging. In a preferred embodiment an MCP or stack of MCPs is used to convert the primary particles into clouds of electrons inducing signals on

30   the conductive members. A gas proportional avalanche chamber may be also used in the conversion stage.

It is advantageous to determine the time-of-flight preferably by calculating the time sums, for

35   example sumxa = tx1a + tx2a and/or sumxb = tx1b + tx2b, yielding the time-of-flight of the first and second primary particles, respectively. A triple

redundancy is achieved by the three conductive members in the x, y and z-directions.

In a preferred embodiment of the present
5   invention a high resistance layer is located between the conductive members and the MCP stack. Preferably, the electron cloud of the MCP is collected by the high resistance layer causing capacitively induced signals on the conductive members. In this case, the MCP
10   stack and the high resistance layer can be inside the vacuum and the conductive members can be outside the vacuum divided by a dielectric wall through which the electromagnetic signals are coupled.

15   In another preferred embodiment three conductive members are provided with an angle of 60° or substantially 60° between each other.

In yet another preferred embodiment the
20   conductive members are printed on a dielectric substrate like a printed circuit board for cheap and simple production.

In a further preferred embodiment a fluorescent
25   screen, preferably a phosphor screen, is provided adjacent the conductive members for creating scintillation light optically visualising the two-dimensional position of the electromagnetic pulse. The secondary scintillation light may be used to
30   further improve multi-hit properties by providing position information when the particle impacts lie within the pulse-pair resolution of the delay-line anode. A CCD-camera or CCD-chip is advantageously used to directly image the scintillation light. An
35   electrically isolated grid is advantageously disposed between the electrically isolated phosphor screen and the conductive members. Preferably the clouds of

electrons generated by the impact of the primary
particle are accelerated before impact on the phosphor
screen to increase the output of secondary
scintillation light.

5

The present invention will now be described
further, by way of example, with reference to the
accompanying drawings in which:

10   Figure 1 shows a top view of a delay-line anode
according to the present invention;

Figure 2 shows a top view of a detector with the
delay-line anode of Figure 1 and a stack of
15   micro-channel plates;

Figure 3 shows a sectional view along line A - A
of the detector of Figure 2;

20   Figure 4 shows a two-dimensional image of a
shadow mask taken with the detector of Figure 2;

Figure 5 shows a sectional view of a second
delay-line anode according to the present
25   invention with a phosphor screen;

Figure 6 shows a top view of conductive members
of a third delay-line anode according to the
present invention;

30

Figure 7 shows a position diagram of the delay-
line anode of Figure 1; and

Figure 8 shows a position diagram of a prior art
35   delay-line anode.

Figure 1 shows a first exemplary embodiment of a

delay-line anode 1 according to the present invention
using a crossed wire technique. The anode 1 comprises
a metallic holder plate 2, which is preferably made of
stainless steel, aluminium or a copper alloy. The

5   holder plate is uniformly hexagonal having six edges
2a to 2f. On each of the edges 2a to 2f a ceramic rod
3a to 3f is mounted, respectively. The six ceramics
rods 3a to 3f preferably have groves (not shown) to
fix six metallic wires 4a, 4a', 4b, 4b', 4c, 4c'

10   forming three wire pairs 4a and 4a', 4b and 4b', 4c
and 4c', respectively. The wire pairs 4a and 4a', 4b
and 4b', 4c and 4c' are wound around the holder plate
2 and are supported by the ceramic rods 3a and 3d, 3b
and 3e, 3c and 3f, respectively, which are located at

15   opposite edges 2a and 2d, 2b and 2e, 2c and 2f,
respectively of the holder plate 2, thus providing a
mesh-like covering on a portion of the front side
(shown side) and the rear side (not shown) of the
holder plate 2. Each wire pair is wound around the

20   holder in a way that going perpendicular to wire first
comes the wire 4a then 4a', 4a, 4a' and so on. All
wires are insulated from each other and from the
holder plate. Each wire has two terminating ends,
which are fixed and electrically connected by metallic

25   screws going through the holder plate 2 being
insulated from the holder plate by ceramic tubes (not
shown). For example, the two terminating ends of the
wire 4b are fixed by screws 14b and 24b, respectively,
the two terminating ends of the wire 4b' are fixed by

30   the screws 14b' and 24b', respectively. The wires 4a
and 4a', 4c and 4c' are fixed in the same manner. The
wires are be contacted easily at the screws to extract
signals induced on the wires. Thus the anode has
twelve of said screws to fix the twelve terminating

35   ends of the six wires 4a to 4c'. In the inner part of
the anode the three wire pairs cross over each other,
but do not contact each other, being in different

planes as shown in Figure 3. This is because ceramic
rods 3a and 3d are of a first diameter, rods 3b and 3e
are of a second diameter and rods 3c and 3f are of a
third diameter, the first, second and third diameters

5   bring sufficiently different. The ceramic rods may
preferably be made from aluminium oxide or the like.
The holder plate 2 has a round hollow 4. The screws
can be used to contact the anode wires by cables,
typically twisted pair cables (not shown), which

10   cables typically go to a vacuum flange (not shown)
from which the signals are transmitted to the
processing electronics (not shown). When a cloud of
electrons 30 hits a portion of the wires of the anodes
the induced electromagnetic signal is propagating with

15   a velocity close to the speed of light on each wire
pair to the respective terminating ends, and from
there by the cables through the vacuum flange to the
signal processing electronics, which may include
amplifiers, discriminators and TDC channels. Each

20   wire pair serves as one signal propagation line
wherein the wires 4a, 4b, and 4c are put on a more
positive voltage than the wires 4a', 4b' and 4c'.
Therefore the electron cloud 30 is mainly collected by
the wires 4a, 4b, and 4c, which are called signal

25   wires, wherein the wires 4a', 4b' and 4c' are called
reference wires.

Figure 2 shows the delay line anode of Figure 1
together with a stack of MCPs 40. Two MCPs are held

30   between two ceramic rings 41. The ceramic rings 41
are partially coated with nickel to contact the MCPs.
The nickel coating 42 has strips 43 for fixing
contacting cables (not shown) by clamping, screwing,
soldering or the like. The ceramic ring 41 has outer

35   holes 44 and three inner holes 45. The outer holes
are used to screw the two rings together to press the
rings to the MCPs and the MCPs on to each other (see

Figure 3). Glass balls (not shown) can be put between the two ceramic rings in the inner holes, wherein the glass balls are larger than the holes and act as spacer between the ceramic rings. The delay-line anode is shown with only one signal line for simplicity.

Figure 3 shows a sectional view along the line A-A of the device shown in Fig. 2. The anode 1 holds the ceramic rings 41. The wire of the wire pair 4c, 4c' (4c' is not shown) is wound around the anode and the ceramic rings. The wire pairs 4a, 4a' and 4b, 4b' are cut and it can be seen that the three wire pairs are spaced apart from each another and do not make electrical contact with each another. A base plate 10 is fixed to the anode holder by screws 46. These screws 46 are preferably made of an insulating material, such as plastic or a ceramics or the like so as to enable applying different voltages on the anode holder and the base plate. The base plate acts as holder for the ceramic rings which fix the stack of MCPs 40, which is exemplary done by screws 47 here. The screws 47 hold the ceramic rings at the base plate and also fix the MCPs 40 between the two ceramic rings. Fixing the MCPs 40 between the ceramic rings 41 can alternatively or additionally be done by clamps or the like. Two MCPs are shown here as an example. The electron cloud 30 emerging from the rear side 40b of the MCPs 40 is travelling to the delay-line anode and expanding during flight. Then the cloud 30 is collected mainly by the signal wires 4a, 4b, 4c.

Figure 4 shows a two-dimensional image taken by the device illustrated in Figures 2 and 3. The following voltages were applied on the parts of the device:

the front side 40a of the MCPs 40: -2 kV;

the rear side 40b of the MCPs 40: +0 V;

the signal wires 4a, 4b, 4c: +200 V;

the reference wires 4a', 4b', 4c': +100 V; and

5   holder plate 2: +0 V

The MCP was illuminated for 1 hour by an alpha-source and a mesh with hexagonal apertures was mounted between the source and the MCPs, close to the MCPs.

10   Figure 4 shows an integrated positive image (the dark areas mean less intensity).

Figure 5 shows a section through a delay-line anode including a phosphor screen 50 before mounting

15   the ceramic rods 3a to 3f and before winding the signal lines 4a, 4a', 4b, 4b', 4c, 4c' around the anode. An aperture which is nearly as large as the phosphor screen is located in the centre of the holder plate 2. Therefore the screen 50 can be seen from

20   both sides of the anode through the signal lines. A grid 51 is glued on said aperture. The phosphor screen 50 is held between two metal rings 53 and 54 by screws 57. The phosphor assembly is supported on the holder 2 by screws 58 and electrically isolated by

25   ceramic spacers 55 and 56 to enable different voltages to be applied on the phosphor 50 and on the holder 2. A screw 59 is provided to allow electrical connection to the phosphor screen 50 via a wire (not shown). For this embodiment, the potential of the phosphor screen

30   may be held at a high voltage, preferably +500 V to +5 kV relative to the rear side 40b of the MCP, to improve the efficiency of generation of scintillation light. The scintillation by the phosphor screen and the operation of the delay-line anode can function at

35   the same time and the rear side of the phosphor screen can be seen during operation of the MCPs. Multi-hit properties of the detector can be further improved if

a CCD camera or CCD chip is used to image secondary
scintillation from the phosphor screen and hence
provide additional position information.

5   Figure 6 shows an alternatively embodiment of a
component of a delay-line anode 101. Little square
formed conductive members 104 are shown, which are
electrically connected in one direction indicated by
the arrow D. At the edge of the anode, meander formed
10   conductors 105 are provided creating additional delay
for the signal propagation. Contact pads 106 are
provided for connecting a cable or the like. The
conductive members are printed on 50 micron polyimid
foil and three of the foils are put on top of each
15   other by an angle of 60° between the direction of the
connection between the squares. Then the conductive
members are receiving the image charge of the
electromagnetic pulse.

20   The advantages of the device and method according
to the present invention are described in the
following section by an exemplary comparison of the
differences between the prior art delay-line anode
with signal lines and the preferred embodiment shown
25   in Figures 7 and 8.

Figure 7 shows the dead area for the delay-line
anode 110 of Figure 1 of about 140 mm diameter. For
the sake of simplicity only the hexagonal form of the
30   anode (no constructional element) is shown. The anode
includes a first, second and third wire pairs (not
shown) defining a first, second and third conductive
members, respectively. The first wire pair is
perpendicular to the edges 110a and 110d, the second
35   wire pair is perpendicular to the edges 110b and 110e
and the third wire pair is perpendicular to the edges
110c and 110f.

First and second electrons are created by double photo-ionization of helium by absorption of a single photon by synchrotron radiation. The light pulse of the synchrotron source has a duration of below 100 ps which can be treated as infinitely small. The simultaneous emission of the two electrons defines the time $t_0 = 0$. The first and second electrons hit a stack of three MCPs mounted above the delay-line anode 110 after the individual time-of-flights tofa and tofb. The constant time for the secondary electron amplification in the MCP-stack and drift time from a MCP-stack to the anode can be disregarded for these considerations, it is short anyway. First and second electron clouds are created by the MCP-stack. The two-dimensional position of a first electron cloud 111 is illustrated in the centre of the detector, by way of example.

Seven differential amplifiers were used to amplify the signal coupled from the MCP-stack front side and the arriving signals at each two ends of each wire pair. The timing of the amplified signal was precisely taken by a constant-fraction-discriminator. We used two amplifier-constant-fraction-modules DLATR4 from RoentDek GmbH, Germany. Seven TDC channels of a 32-channel TDC (LeCroy 3377) were used. The LeCroy 3377 TDC manual indicates 20 ns dead time for each channel, but we achieved only about 11 ns dead time. All TDC channels were started by the initial somehow delayed synchrotron machine signal. Those skilled in the art are familiar with this concept of precise time-measurement. The following times were measured (if not lost by dead time) by the TDC-channels:

        Channel 1:   tx1a, tx1b at the first terminating
                     end of the first wire pair;

Channel 2: tx2a, tx2b at the second terminating
end of the first wire pair;

Channel 3: ty1a, ty1b at the first terminating
end of the second wire pair;

Channel 4: ty2a, ty2b at the second terminating
end of the second wire pair;

Channel 5: tz1a, tz1b at the first terminating
end of the third wire pair;

Channel 6: tz2a, tz2b at the second terminating
end of the third wire pair; and

Channel 7: tofa, tofb at the MCP front,

where a and b denote the first and second signals
arriving at the TDC inputs, respectively.

The first, second and third wire pairs are
perpendicular to the first 110a, 110d, second 110b,
110e and third 110c, 110f pair of detector edges.

Now we illustrate an exemplary event, where both
electrons arrive at the detector at the same time,
i.e. tofa = tofb and the first electron 111 hits the
detector at the centre. However, the time-of-flight
of the second electron can still be reconstructed by
one of the time sums: sumxb = tx1b + tx2b, sumyb =
ty1b + ty2b or sumzb = tz1b + tz2b. Thus, only one of
these is enough to easily reconstruct tofb, for
example as tofb = sumxb/2 - Tx, where Tx is the total
signal propagation time from the first to the second
terminating end of the first wire pair. For the y-
and z-directions it reads accordingly to fb = sumyb/2
- Ty and tofb = sumzb/2 - Tz. The three bars 112a,
112b and 112c subtended by the dotted lines correspond
to the electronic dead time. Consequently, for
example, if the second electron hits the detector
within the bar 112a, tx1b and tx2b are lost and
consequently sumxb is lost. Thus, tofb can be

reconstructed, when the second electron hits the detector outside the hexagon 112.

For determining two linearly independent position components of the second electron at least two times being from different wire pairs shall be detected. This can be, for example, tx1b and ty1b or any other pair of signal times which are not from the same wire pair. The fact that the two position components are not perpendicular to each other is not a problem, as long as they are linearly independent, i.e. the wire pairs are not parallel. Therefore, having 60° between each of the wire pairs (as shown here) is a preferable but not necessary configuration. The Cartesian coordinates can easily be calculated by trigonometric functions.

However, having two position components of each of the first and second electrons is still not enough to determine the two-dimensional position of both first and second electrons. This information yields four position components xa, xb and ya, yb, but one does not know which two belong together, i.e. one cannot know if the first electron has position (xa, ya) and the second electron has (xb, yb) or if the true combination is (xa, yb) and (xb, ya). This is due to the fact that one does not *a priori* know if the secondly measured times indicated by the "b" belong to the second electron, because signals from an earlier electron can arrive later at a terminating end due to different positions. To decide which of the two possibilities is the true one, one additionally needs the time sums, sumxb and sumyb.

When tx1a, tx1b, ty1a, ty1b, tx2a, tx2b, ty2a and ty2b are measured one calculates the time sums for both combination possibilities, i.e. sumxa' = tx1a +

tx2a and sumxb' = tx1b + tx2b or sumxa'' = tx1a + tx2b
and sumxb'' = tx1b + tx2a. For the y-direction one
proceeds accordingly, i.e. sumya' = ty1a + ty2a and
sumyb' = ty1b + ty2b or sumya'' = ty1a + ty2b and
5   sumyb'' = ty1b + ty2a. Thus, one receives for both x-
and y-directions two combination possibilities, the
first one indicated by the prime and the second one
indicated by the double prime. For the x- and y-
directions one additionally knows that the true time
10   sums for the same electron must be identical, since
the true time sum is twice the time-of-flight plus the
constant total propagation time on the wire pair (Tx,
Ty or Tz) and the half the time sum of the first
arriving electron minus the respective total
15   propagation time is equal to the measured tofa at
channel 7. Accordingly, one can decide for each of
the sumxa, sumxb, sumya and sumyb if the single or
double primed solution is the true one and which one
belongs to the first and second arriving electrons.
20   If, for example, the sumxa'', sumxb'', sumya'' and
sumyb'' are the true combinations, one calculates the
true time-of-flights tofa = sumxa''/2 - Tx = sumya''/2
- Ty and tofb = sumxb''/2 - Tx = sumyb''/2 - Ty.

25   The true positions xa, ya, xb and yb of the two
electrons are computed accordingly as:

         xa = vx * (tx1a - tx2b);
         xb = vx * (tx1b - tx2a);
30   ya = vy * (ty1a - ty2b); and
         yb = vy * (ty1b - ty2a).

         Now, one knows uniquely that tofa, xa and ya
belong to the first electron, and tofb, xb and yb
35   belong to the second electron, resulting in the
desired tuples time-of-flight and two-dimensional
position of each single particle hitting the detector.

Accordingly, the time-of-flight and the two-
dimensional position of at least two particles can be
determined, even if they both hit the detector at
exactly the same time, as long as the second particle
impinges on the detector outside a star-formed dead
area 113 around the first particle formed by the
overlap area of at least two of the three dead-time
bars 112a, 112b and 112c.

Figure 8 shows a schematic drawing of a prior art
square delay-line anode 120 of about 80 mm x 80 mm
size. The anode was used for the same experiment as
the anode according to the present invention.

The position of a first electron 121 is shown in
the centre of the anode 120. A first and second wire
pair (not shown) is parallel to the edges 120a, 120c
and 120b, 120d, respectively. When the second
electron hits the detector, time-of-flight and the
position of the second electron can only be determined
when the second particle arrives at the detector
either:

at least after a time which is larger than the
electronic dead-time of about 11 ns to 20 ns,
depending on the TDC used; or

at least after a time which is larger than the
resolution of tofa - sumxa/2 - Tx, which is some
kind of internal timing resolution of the
detector, typically from about 1 to 2 ns full
width half maximum (FWHM), and the second
electron must arrive outside the cross-shaped
area 122.

Accordingly, the conventional prior art anode

cannot resolve particles with a time difference
smaller than typically 1 to 2 ns, but even if the time
difference is larger than that, the area 122 in which
the position or time information of the second

5   particle (in some cases even additionally of the first
particle) is lost, is considerably larger than with
the delay-line anode according to the present
invention.

10   Thus, the general multi-hit properties and the
pulse-pair resolution are improved by the anode
according to the present invention compared with the
conventional prior art anodes.

15   The multi-hit properties can be further improved
by using a phosphor screen for additional direct
imaging of secondary scintillation on a CCD camera or
a CCD chip to provide particle positions. The
available times from the delay-line can then used to

20   calculate arrival times for the particles.

It will be appreciated that the present invention
is not restricted to the exemplary embodiments but can
be embodied in various forms of delay-line anodes and

25   the number of conductive members can be increased to
further improve the pulse-pair resolution and/or the
multi-hit properties. In particular, when more than
two particles need to be detected, i.e. n particles,
it is envisaged that n + 1 conductive members may be

30   provided.

35

Claims:

1. A device for detecting the position of a particle, the device comprising a delay-line anode (1) which includes at least first, second and third non-parallel conductive members (4a, 4b, 4c) for receiving electromagnetic pulses (30), each one of the conductive members (4a, 4b, 4c) forming a propagation line for electromagnetic signals and having a first and a second terminating end, at least some of which provide a propagated signal to an electronic analyser.

2. A device as claimed in claim 1 further comprising a secondary electron multiplier (40), preferably a micro-channel plate or a stack (40) thereof, or a micro-sphere plate or a stack thereof, and/or a gas proportional chamber.

3. A device as claimed in claim 1 or 2 further comprising six amplifiers, preferably differential amplifiers, each one assigned to one of said terminating ends of said conductive members (4a, 4b, 4c).

4. A device as claimed in claim 3 further comprising six discriminators, preferably constant-fraction discriminators, each one assigned to one of said amplifiers.

5. A device as claimed in any one of the preceding claims further comprising six or more time-to digital-converter (TDC) channels, preferably multi-hit TDC channels, each one assigned to one of said terminating ends and/or to said amplifiers and/or said discriminators.

6. A device as claimed in claim 5 further comprising

a microprocessor computer for processing the timing
information of the TDC channels and for visualising
the position and/or time of creation of said
electromagnetic

5   pulse.

7.   A device as claimed in any one of the preceding
claims, wherein said first, second and third
conductive members (4a, 4b, 4c) have an angle of 60°

10   or approximately 60° between each other.

8.   A device as claimed in any one of the preceding
claims, wherein said first, second and/or third
conductive members comprise a first, second and third

15   pair of conductors (4a, 4a', 4b, 4b', 4c, 4c'),
respectively, preferably wire pairs forming a Lecher
line, preferably wound around a holder plate (2).

9.   A device as claimed in any one of claims 1 to 7,

20   wherein said first, second and/or third conductive
members (4a, 4b, 4c) are provided on a dielectric
substrate, preferably forming a meander line.

10. A device as claimed in any one claims 1 to 7,

25   wherein said first, second and/or third conductive
members are provided on a dielectric substrate,
forming a plurality of planar extended structures
(104) being partially electrically connected.

30   11. A device as claimed in any one of the preceding
claims, further comprising a fluorescent screen,
preferably a phosphor screen (50), disposed adjacent
to the three conductive members (4a, 4b, 4c).

35   12. A device as claimed in claim 11, further
comprising a CCD camera or CCD chip for imaging
secondary scintillation from the fluorescent screen.

13. A device as claimed in claim 11 or claim 12, wherein an electrically isolated grid is disposed between an electrically isolated fluorescent screen, preferably a phosphor screen, and the three conductive members (4a, 4b, 4c).

14. A device as claimed in any one of the preceding claims further comprising a high resistance layer located close to said conductive members (4a, 4b, 4c) for receiving said electromagnetic pulse.

15. A device as claimed in any one of the preceding claims, wherein the mean pulse-pair resolution is approximately 5 ns or less, more preferably approximately 2 ns or less.

16. An atom probe instrument for microstructural and microchemical analysis of materials, the instrument comprising a device as claimed in any one of the preceding claims.

17. A method for detecting the spatial position of an electromagnetic pulse, which method comprises the following steps:

(a) providing a device as claimed in any one of claims 1 to 15;

(b) receiving an electromagnetic pulse on a portion (30) of said first, second and/or third conductive members (4a, 4b, 4c);

(c) propagating said electromagnetic pulse on said conductive members (4a, 4b, 4c); and

(d) determining the local position of said portion

(30) of said first, second and/or third
conductive members by measuring the time of the
arrival of said electromagnetic pulse at said
first and/or second terminating ends.

18. A method as claimed in claim 17, wherein said
electromagnetic pulse is created by a moving cloud of
charged particles (30), preferably a cloud of
electrons.

19. A method as claimed in claim 17 or claim 18,
wherein a portion of said first, second and/or third
conductive members (4a, 4b, 4c) comprise a pair of
conductors (4a, 4a', 4b, 4b', 4c, 4c'), preferably
metallic wires forming a Lecher line.

20. A method as claimed in any one of claims 17 to 19
further comprising amplifying said electromagnetic
pulse by a secondary electron multiplier (40),
preferably a micro-channel plate or a stack thereof
(40), or a micro-sphere plate or a stack thereof,
and/or a gas proportional chamber.

21. A method as claimed in one of claims 17 to 20
further comprising amplifying said electromagnetic
pulse using six amplifiers, preferably differential
amplifiers, each amplifier being assigned to one of
said terminating ends of said conductive members (4a,
4b, 4c).

22. A method as claimed in claim 21 further
comprising six discriminators, preferably constant-
fraction discriminators, each discriminator being
assigned to one of said amplifiers.

23. A method as claimed in one of claims 17 to 22,
wherein six or more TDC channels are used, preferably

multi-hit TDC channels, for measuring the arrival
times of said electromagnetic pulse at said
terminating ends.

5   24. A method as claimed in any one of claims 17 to
23, wherein the spatial position of said portion (30)
is determined by the time differences of the arrival
of said electromagnetic pulse at said first and second
terminating ends.

10

25. A method as claimed in one of claims 17 to 24,
wherein a fluorescent screen, preferably a phosphor
screen (50), is provided adjacent the three conductive
members (4a, 4b, 4c).

15

26. A method as claimed in claim 25, wherein a CCD
camera or CCD chip is provided for imaging secondary
scintillation from the fluorescent (50) screen to
thereby provide further information on the spatial
20   position of the electromagnetic pulse.

27. A method as claimed in one of claims 17 to 26,
wherein the time of inducing said electromagnetic
pulse on said conductive members (4a, 4b, 4c) is
25   determined, preferably by taking a signal from a
micro-channel plate (40), front or rear side (40a,
40b), or from an anode holder (2) or from a
fluorescent screen (50).

30   28. A device for detecting the position of a particle
substantially as hereinbefore described with reference
to or as illustrated in any one of Figures 1 to 7.

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INVESTOR IN PEOPLE

| Application No: | GB 0003261.5 | Examiner: | Martyn Dixon |
| Claims searched: | all | Date of search: | 23 May 2000 |

**Patents Act 1977
Search Report under Section 17**

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

   UK Cl (Ed.R): H1D (DF,DJ,DGGX,DHAX,DHE,DHX,DMF)

   Int Cl (Ed.7): H01J; G01T

Other: Online: EPODOC,WPI,JAPIO,INSPEC

Documents considered to be relevant:

Category	Identity of document and relevant passage	Relevant to claims
Y	US 5644128 A (Ionwerks) see especially col 6, lines 58-62	1-6,8-10, 16-24,27
Y	US 5347132 A (Wisconsin Alumni Research) see fig 11	1-6,8-10, 16-24,27
Y	US 5347130 A (Laboratorium Prof Dr Rudolf Berthold) see e.g. fig 1	1-6,8-10, 16-24,27
Y	US 5061850 A (Wisconsin Alumni Research) see figs 11 and 12 and col 18, lines 16 *et seq*	1-6,8-10, 16-24,27
Y	US 4870282 A (Xenos) see e.g. fig 2	1-6,8-10, 16-24,27

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
		E	Patent document published on or after, but with priority date earlier than, the filing date of this application.
&	Member of the same patent family		